United States Geological Survey,
Rock Magnetics Laboratory (Building 9B)
345 Middlefield Road
Menlo Park
San Mateo County
California

HAER No. CA-173

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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Western Region
Department of the Interior
San Francisco, California 94107

HISTORIC AMERICAN ENGINEERING RECORD

UNITED STATES GEOLOGICAL SURVEY

ROCK MAGNETICS LABORATORY (BUILDING 9B)

HAER No. CA-173

Location: The Rock Magnetics Laboratory is located in Building 9B, U.S. Geological Survey, at 345 Middlefield Road in Menlo Park, California.

USGS Quad: Palo Alto (7.5') 1961. Photorevised: 1968 and 1973. Township 5S Range 3W; Unsectioned.

UTM Coordinates: Zone 10.
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Date of Construction: Building 9B was constructed between 1943 and 1954 but became the Rock Magnetics Laboratory in 1959. The equipment housed in Building 9B was constructed between 1959 and 1966. Much of the equipment continues to be used today, and modifications have been made.

Present Owner: The Rock Magnetics Laboratory is owned by the U.S. Department of the Interior, U.S. Geological Survey (USGS).

Present Use: The Rock Magnetics Laboratory and the associated equipment are being used by geologists at USGS for their original purpose.

Significance: The temporary building, which was originally a temporary military hospital, became, in 1959, the home of the Rock Magnetics Laboratory and the site of revolutionary research in the field of earth sciences. This research, carried out by Richard Doell, Allan Cox, and Brent Dalrymple, culminated in 1966 with a time scale for reversals of the earth's magnetic field. This discovery contributed significantly to evidence in favor of plate tectonics. The Rock Magnetics Laboratory was designated a National Historic Landmark on October 12, 1994. Designation as a National Historic Landmark automatically places the property in the National Register of Historic Places. The period of significance for the Rock Magnetics Laboratory is from 1959 to 1966.

Prepared by: Dana McGowan, Leslie Fryman, and Shahira Ashkar
Jones & Stokes Associates, Inc.
2600 V Street, Suite 100
Sacramento, CA 95818-1914

and

David G. De Vries
Mesa Technical
2630 Hilgard
Berkeley, CA 94709-1002

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PART 1. INTRODUCTION

This report and the attached photodocumentation have been prepared to mitigate the adverse effects of facility remodeling on a temporary building (Building 9B) belonging to the U.S. Geological Survey's (USGS's) Menlo Park facility, which houses the Rock Magnetics Laboratory. Building 9B will be demolished, and the equipment will be moved to the new building constructed to house the laboratory. The Rock Magnetics Laboratory was designated a National Historic Landmark on October 12, 1994. Designation as a National Historic Landmark automatically places the property in the National Register of Historic Places. This mitigation is being conducted in compliance with Section 106 of the National Historic Preservation Act (NHPA), and a memorandum of agreement between USGS, the California State Historic Preservation Officer (SHPO), and the Advisory Council on Historic Preservation.

For the descriptive sections of this document, most of the information was obtained through personal communication with Sherman Gromme, Ed Mankinen, and Brent Dalrymple. Their help in describing the materials and functions of the geophysical equipment was invaluable.

PART 2. HISTORICAL SIGNIFICANCE

In 1915, Alfred Wegener proposed the theory of continental drift. He believed that all the continents were connected during the Paleozoic Era and dubbed that inclusive landmass Pangea. However, without an explanation for how the continents moved, Wegener's theory remained an interesting and untestable idea. The evidence for continental drift or, more accurately, plate tectonics came from studies of sea floor spreading, young rock dating, and paleomagnetics.

Paleomagnetics is the study of the earth's ancient magnetic field. The term "paleomagnetics" came into use in the 1950s. Before that, the field was referred to as rock magnetics. The earliest work in paleomagnetics was directed toward establishing the origin and history of the earth's magnetic field. Not much thought was given to the applications (geological or otherwise) of the research (Verhoogen 1985:401). Early researchers did not expect or direct their work toward testing the theory of continental drift.

The earth has a magnetic field that results from energy generated in the liquid iron and nickel of the earth's outer core. Because of its liquid origin, this magnetic field is dynamic. The present polarity of the earth's magnetic field produces lines of force toward geographic north, as demonstrated by use of a simple field compass. In the distant past, the polarity of this magnetic field has reversed numerous times. During such times, a compass needle would point toward geographic south. These periods of "normal" and "reverse" polarity, called epochs, have not been regularly spaced in time. The average rate of polarity transitions is roughly five reversals per a million years.

Epochs are random and are punctuated by "events" of opposite polarity. Reversals occur instantaneously, geologically speaking, taking 2,000-8,000 years (Tarling 1983:200).

Because rocks contain magnetic minerals, evidence of the polarity of the earth's magnetic field at the time the rocks were formed is locked in them (Cox and Hart 1986). When volcanic rocks are molten, the magnetic particles in them align to the polarity of the earth's magnetic field. As the rock cools, it solidifies and then passes through a point called the Curie temperature, at which the rock begins to acquire a thermoremanent magnetization. Curie temperatures vary from mineral to mineral. Above the Curie temperature, the rock remains solid, but thermal agitation prevents magnetic alignment or ordering of atoms within the magnetic minerals. Magnetism in sedimentary rocks is acquired in a similar fashion. As minute grains of magnetic materials are deposited, they align themselves to the ambient magnetic field and are trapped in that position by the processes of compaction and cementation (lithification). This type of magnetization is called depositional remanent magnetism (Cox and Hart 1986). In addition, both igneous and sedimentary rocks can undergo chemical changes that produce magnetism. These and other types of secondary magnetization must be stripped away through magnetic cleaning processes in the laboratory before the original thermoremanent (or depositional remanent) magnetization can be determined (Cox and Hart 1986, Tarling 1983).

From the mid-1930s to the late 1940s, numerous researchers in Germany, Japan, France, and elsewhere studied the magnetism of rocks (Verhoogen 1985:401). Although most studies concentrated on volcanic rocks, the Department of Terrestrial Magnetism of the Carnegie Institute examined the magnetism of varves (annual layers of silt deposited in lakes or other bodies of still water) and marine sediments. This broadened the field of interest.

As early as 1957, the first steps were being taken by reversalists (scientists studying polarity reversals). Scientists at Edmonton began reversal time scale experiments. The first effort to define a time scale of magnetic reversals was made by Martin Rutten of the Mineralogisch-Geologisch Institut, Rijksuniversiteit, Utrecht (in Holland) in 1959 (Glen 1982:132-138). He put together dates acquired by Evernden and Curtis of the University of California, Berkeley (UCB). The resulting scale was very rough.

In the middle to late 1950s, the directionalists in England were investigating questions of ancient magnetic pole positions. Their polar wander data "increasingly suggested continental displacements" (Glen 1982:359). Keith Runcorn came to play a dominant role among the English directionalists. As a group, they had "long been convinced of field reversals" but did not give priority to establishing a time scale based on them (Glen 1982:359). Their work became the impetus for other groups, including Verhoogen and his students at UCB, to investigate field reversals.

Like most institutions, UCB had no research program directed toward the resolution of the question of continental drift until Dr. Verhoogen implemented the rock magnetics program with

Richard Doell as his first student. Doell's earliest projects were not on reversals, but on paleomagnetic poles, chemical remanence, and secular variation. Cox began paleomagnetic studies at UCB shortly after Doell did. They did not begin the rock magnetics project at USGS until the late 1950s.

Self-Reversal versus Field Reversal

In the early 1900s, Bernard Brunhes and Pierre David observed that the magnetism of several lava flows in the Auvergne region of France either was aligned with the present magnetic field or was almost exactly opposite to it. This discovery heralded the beginning of the study of reversely magnetized rocks and the discussions over their meaning. Motonori Matuyama, in 1929, and Paul L. Mercanton, in 1933, both suggested that the earth's magnetic field may have been reversed at one time.

When inverse magnetizations were found, they were often attributed to physical and chemical conditions peculiar to particular rocks or rock formations. These data were presumed to have no direct bearing on the past directions of the earth's magnetic field. However, by the mid-1950s, British paleomagnetists were less convinced that these data were irrelevant (Verhoogen 1985:402). They generally believed that these different magnetizations could be explained by polar wander and continental drift. American paleomagnetists, as represented by Cox and Doell in their review (1960), held that differences in magnetic directions could be attributed to pole wander and errors in stratigraphic control and dating.

Basically, the problem posed by these anomalous rocks was whether they were the product of self-reversal or of a field reversal. Was there something inherent in the physical or chemical makeup of the rock or rock formation that caused its magnetism to reverse? Or has the earth's magnetism been reversed in the past? There was a great deal of preference for the former explanation simply because it seemed more plausible, but unlike the question of continental drift, both of these hypotheses were testable.

If reversely magnetized rocks were the results of self-reversals, these rocks would come from all time periods and would be more likely to have physical or chemical attributes in common. If they were the result of a field reversal, all rocks, of all types, from the same period should be magnetized in the same direction regardless of their location on the globe. Additionally, it should be possible to find, in certain complete stratigraphic sections, transitions from one polarity to the other.

The primary difficulty in approaching such an experiment was chronometric control. Until the 1960s, there was no dating method suited to the time intervals that paleomagnetists must deal with (Glen 1982). Polarity reversals could take place in a few thousand years, and as little as 100,000 years could pass before the next reversal occurred (Verhoogen 1985). No dating method available at that time could provide time resolution for such "young" dates (i.e., less than 5 million years ago). But in the 1950s, scientists at UCB made giant strides in equipment for potassium-argon (K-Ar) dating, and by the 1960s there was sufficient control to produce reliable dates. The methods and instrumentation necessary to obtain magnetic data were available in the 1950s, but the radiometric techniques were unavailable until the 1960s.

The first research program aimed specifically at resolving the issue of self-reversal versus field reversal was conceived at UCB in the late 1950s and undertaken at the USGS research center at Menlo Park by Allan Cox and Richard Doell. They devised an elegant experiment to examine this issue. By comparing the magnetism and dates of rocks, they sought to prove, or rather not to disprove, that the earth's magnetic field had reversed in the past. In addition to demonstrating that all the samples from a particular time period were magnetized in the same direction, they also constructed a time scale. Thus, as the data began to accumulate, the question shifted from whether there had been field reversals to whether they occurred at a regular frequency.

Cox and Doell later invited the collaboration of Brent Dalrymple, who was trained in K-Ar dating.

Potassium-Argon Dating

K-Ar dating is the most effective method for dating young rocks. It is based on the decay of potassium-40 (K-40) to argon-40 (Ar-40). The half-life of K-40 is 1.25 billion years. A half-life is the time it takes for half of a sample to decay to another isotope. A half-life of 1.25 billion years allows for measurable quantities of argon-40 in rocks from a few thousand years old to more than 4 billion years old (Glen 1982:17).

By 1948, K-Ar dating seemed promising, but there were still major gaps in information and advances in technique had yet to occur. There was no method for extracting and handling argon, and knowledge of the half-life and branching ratios of K-40 was incomplete (Glen 1982:23-27). In the early 1950s, some dates were obtained on older rocks, which were the least difficult to date. Work began on dating the oldest rocks, meteorites.

Meanwhile, at UCB, geologists John Verhoogen and Francis J. Turner were interested in dating young rocks. At the suggestion of the geology faculty, a UCB physicist recruited John H. Reynolds from the University of Chicago in 1950. Reynolds had been working on mass spectroscopic studies of branching ratios and double beta decay (Glen 1982:29). In the mid-1950s, he developed the Reynolds type mass spectrometer. K-Ar dating and the mass spectrometer were first applied to geological problems with the aid of Robert Folinsbee at UCB. During the same time period, Garniss Curtis (UCB geology faculty member) and Jack Evernden (UCB geophysics faculty member) were dating increasingly younger rocks (Glen 1982:50).

By 1956, the questions of potassium-40's branching ratio and decay constant were largely resolved, but the questions of retentivity or diffusion in many minerals remained (Glen 1982:62). Other major problems in 1956 and 1957 were how to select appropriate materials, optimize analytic procedures, and, most important, reduce contamination (Glen 1982:62). In 1958, Evernden devised a technique to reduce contamination, and by the early 1960s, young rock daters from UCB were highly sought after (Glen 1982:65).

Doell, Cox, and Dalrymple

Richard Doell was born in California in 1923. He was not a particularly devoted student and attended University of California, Los Angeles, and UCB, without completing a degree. Medical problems kept him out of the Naval Air Force, but the Army drafted Doell in 1942 and sent him to the University of Oklahoma to study civil engineering. He was discharged in November 1945. Doell became involved in geology fortuitously when he was hired by the United Geophysical Company in Santa Barbara. He applied not so much out of interest but because he met the requirements, having drafting experience and a little knowledge of physics and math. After working there for more than two years, he decided to return to school and pursue a degree in geology at UCB. In 1950, he changed his major to geophysics because he had already completed most of the required physics and math courses. He developed an interest in instruments for recording magnetic properties and, through a seminar with Dr. John Verhoogen, he built a magnetometer. Doell continued at UCB under the tutelage of Dr. Verhoogen and Dr. Perry Byerly and completed his dissertation, *Remanent Magnetism in Sediments*, in June 1955. In summer 1955, he went to the University of Toronto as a member of the geophysics faculty. In fall 1956, he went to the Massachusetts Institute of Technology (MIT) as an assistant professor. After three years at MIT, he moved to California and joined Allan Cox in the Rock Magnetics Project at USGS (Glen 1982:141-154).

Allan Cox was born in 1926 in Santa Ana. In high school, he became interested in chemistry. After graduating from high school, he attended a summer session at UCB before joining the Merchant Marines. After three years, he was discharged and reenrolled at UCB as a chemistry major. His interest in geology was sparked and nurtured by summer work in Alaska with Clyde Wahrhaftig and USGS. In spring 1951, he suffered a period of emotional distress and and went on an extended hike in lieu of taking his final exams. Because he did not complete his courses, he lost his deferment and was drafted. He spent two years in the Army stationed in New Jersey, where he trained in operation and maintenance of microwave communication equipment. Upon discharge, he went back to school to study earth sciences at UCB. His dissertation was on reversals in the Snake River Plain (Glen 1982:154-174).

Cox and Doell met in 1955, when Doell was completing his dissertation and Cox was a senior undergraduate (Glen 1982). By summer 1958, they had laid plans for a long-term cooperative effort at the USGS facility in Menlo Park. Cox had continued as a part-time employee for USGS for several years and had remained in touch with the chief of the geophysics branch, James Balsley. While Doell was still in Massachusetts, Cox acquired a building at the facility at Menlo Park. The building was one of several temporary buildings and, because of its unofficial status, they were able to modify it without significant paperwork. Balsley was interested in the project and aided in funding and other aspects. He assigned Major Lillard, a master instrument builder and technician from Washington, D.C., to the Rock Magnetics Project (Glen 1982:180). Thus, the building was acquired and partially equipped before Doell reached Menlo Park in March 1959 (Glen 1982:178).

Doell and Cox enlisted the help of Brent Dalrymple, a young geophysicist out of Berkeley, with experience in K-Ar dating (Glen 1982:189-206). Dalrymple was born in Alhambra, California, in 1937. He did his undergraduate work at Occidental College. Although he entered college as a physics major, he graduated with a degree in geology. He attended graduate school at UCB in 1959. Originally, his interests were in geomorphologic and petrologic problems, but teaching a summer field course with Curtis and Evernden piqued his interest in radiometric dating. The next fall, Dalrymple was in the UCB laboratory learning K-Ar dating from a senior graduate student named John Obradovich. Also receiving instruction in K-Ar dating on that first day was Ian McDougall, who would later provide friendly Australian competition for the Menlo Park group.

Dalrymple met Cox and Doell for the first time during summer 1961 but did not become involved with the Rock Magnetics Project until late 1962, when he accepted a job offer from Richard Doell (Glen 1982:189-206). He officially came on staff when the National Science Foundation awarded him a grant in June 1963. Because the Rock Magnetics Project did not have its own dating equipment, it was necessary to "bootleg" argon samples to UCB for analysis or to share the facilities of the Isotope Geology Lab. After the Rock Magnetics Project was provided its own instruments and its own K-Ar dater in early 1964, work sped up dramatically.

The Data

To accumulate the data necessary to construct these polarity reversal time scales, cores had to be collected from lava flows, and the dates and magnetizations of these cores had to be determined. It is helpful to list, generally, the steps that were taken to derive the data.

Cores were collected in the field by Cox, Doell, and Dalrymple. Reversely magnetized samples can be recognized at the outcrop using a battery-powered transistor, fluxgate type of magnetometer (Doell and Cox 1967a). The cores were drilled from lava flows using an adapted chainsaw motor. To keep the core and tool cool and to keep the drill bit from seizing, or stopping, water was run through the core drill bit. The drill was removed from the rock while the core was still attached. A nonmagnetic orienting device was placed over the attached core, and the angle from horizontal and the direction were determined and noted. The core was removed from the rock with a nonmagnetic chisel, and it was marked with copper wire. After the core was removed from the orienting device, a diamond scribe and permanent marker were used to indicate north, and hash marks were used to indicate which end was up. Six to eight cores were taken per flow (Cox et al. 1967). Back in Menlo Park, these cores were cut into a number of smaller cylindrical samples and used to determine both the age and the magnetic orientation of the lava flow.

In the field, Dalrymple would sometimes make thin sections and examine them with a microscope to select unaltered flows for sampling. To determine the age of a rock using the argon mass spectrometer, a sample of argon must be extracted from the rock. This determination was made by melting a part of the core in an argon extractor. The argon gas could then be introduced into the mass spectrometer and a date could be obtained. Generally, younger rocks are harder to date than older rocks.

To determine the original thermoremanent magnetization of rocks, it is necessary to strip away other secondary magnetizations. Thermoremanent magnetization tends to be weak but very stable. Demagnetization can be accomplished in two ways. In thermal demagnetization, the specimen is heated in a field-free zone and then cooled. "Softer", less coercive magnetization is erased at lower temperatures by randomizing the magnetic moments of the grains bearing it. In AC demagnetization, the specimen is tumbled in an alternating current. The current is reduced as the specimen continues to spin, leaving less coercive materials aligned in a seemingly random fashion. After the specimen has been demagnetized, the direction and intensity of the thermoremanent magnetization are determined using the spinner magnetometer.

The Scales

Cox, Doell, and Dalrymple published their first geomagnetic reversal time scale in *Nature* in June 1963 (Glen 1982:226-232). It was entitled "Geomagnetic Polarity Epochs and Pleistocene Geochronology." Only nine dates served to construct this first scale. The scale had been rushed to some extent to beat the Australian competition.

Ian McDougall, who had begun K-Ar dating studies with Dalrymple at UCB, returned to Australia and began working in Canberra, collaborating with a number of paleomagnetists (Glen 1982:206-222). Originally, he did not work on reversal studies, but after he entered the field, he, in collaboration with others, succeeded in producing successively more complete versions of a polarity reversal time scale in competition with Cox, Doell, and Dalrymple. McDougall's first two scales were published with Don Tarling.

Four months after Cox, Doell, and Dalrymple published their first scale, McDougall and Tarling came up with a more complete one (Glen 1982:232-235). Their article, "Dating of Polarity Zones in the Hawaiian Islands," appeared in the October 5, 1963, issue of *Nature*. Although the results were congruent with Cox, Doell, and Dalrymple's earlier scale, two possible additional polarity changes were indicated. The more complete Australian data indicated that the reversals occurred with varying frequency, as opposed to the million-year intervals suggested by Cox, Doell, and Dalrymple.

Sherman Gromme and Richard L. Hay, both of UCB, published a paper in *Nature* in November 1963 (Glen 1982:235-237). Dates from Olduvai Gorge provided what they thought was the boundary between the last reversal and the normal period before that (N2-R1 boundary). This boundary would later prove to be the Olduvai event.

Over the next few years, progressively more accurate scales were presented, resulting from more data. Authors included Cox, Doell, and Dalrymple (in varying order); McDougall and Tarling; Gromme and Hay; and Evernden, Savage, Curtis, and James (Glen 1982:226-266). During this time, the precedents for naming and referring to polarity epochs and events were set.

On May 20, 1966, Doell and Dalrymple published "Geomagnetic Polarity Epochs: A New Polarity Event and the Age of the Brunhes-Matuyama Boundary" in *Science* (Glen 1982:261-266). Allan Cox was abroad when the research was undertaken. The paper defined the Jaramillo event and set the Brunhes-Matuyama boundary at 0.7 million years ago. This time scale was not "complete." Many additions have been made, and the scale has been extended further back in time in the last 30 years. However, this is the scale that was recognized by Fred Vine as the pattern of magnetic anomalies on the ocean floor. The definition of the Jaramillo and the fine tuning of the Brunhes-Matuyama boundary were the last in a series of discoveries that made the time scale recognizable to Fred Vine and other scientists investigating sea floor spreading.

Seafloor Spreading

In 1963, Fred Vine and Drummond H. Matthews of the University of Cambridge and, independently, Lawrence W. Morley of the Geological Survey of Canada, advanced a "highly speculative and poorly received" hypothesis (Glen 1982:269). This hypothesis held that the ocean floor is imprinted with the record of field reversals in the form of a sequence of alternating magnetized stripes with widths proportional to the alternating intervals of the polarity reversal scale. These stripes were formed as the newly created ocean floor spread from midoceanic ridges. Until the 1960s, magnetic anomalies on the seafloor were most often interpreted in terms of differences in rock types and introduced magnetism.

Ironically, much of the data used to demonstrate seafloor spreading were accumulated by researchers from Columbia University's Lamont Geological Observatory, most of whom disagreed with the theory of continental drift (Glen 1982:312-353). The Lamont facility sponsored several large-scale ocean floor mapping projects. Fred Vine was at Lamont in February 1966 and saw the Eltanin 19 profile, which was compiled by Walter Pitman, a graduate student there. Vine knew the significance of this profile and how it might be integrated with other data in support of his hypothesis.

In the December 1966 issue of *Science*, Vine successfully correlated Doell and Dalrymple's reversal time scale with the magnetic anomaly profiles across midocean ridges. Confirmation from a third source came when the same polarity intervals were demonstrated in deep sea sediment cores (Glen 1982:269). Other evidence for seafloor spreading included "structures indicative of tension and high values of heat flow at the axes of the mid-ocean ridges" and the young age of seafloor rocks (Glen 1982:269). These correlations not only supported the theory of seafloor spreading, but they demonstrated that seafloor spreading occurs at a constant rate, although that rate differs from ridge to ridge. Because there was a time scale, the rate of spreading at particular midocean ridges could be determined.

Conclusion

Between 1959 and 1966, Allan Cox, Richard Doell, and G. Brent Dalrymple, working at the Menlo Park USGS facility, accumulated data, and between 1963 and 1966, they constructed and published the results of their polarity reversal experiment in the form of a number of time scales. They originally gave no thought to the ramifications of their research, but it was instrumental in the confirmation of seafloor spreading and provided crucial evidence for plate tectonics. On April 8, 1971, Allan Cox and Richard Doell shared the Vetleson Prize with Keith Runcorn (Glen 1982:360-361). Thus, both directionalists and reversalists were honored for their considerable contribution to this revolution in earth sciences.

PART 3. PHYSICAL DESCRIPTION

Rock Magnetics Laboratory

The building where the reversal time scale research took place at the USGS facility in Menlo Park is a World War II-era cantonment structure constructed as part of the Dibble General Army Hospital between 1944 and 1946. During that time, this temporary wood-frame building functioned as an overflow medical ward and was probably one of several emergency facilities erected at Dibble to accommodate the flow of evacuees from the Pacific Theater during World War II. After the Army hospital closed, USGS acquired a portion of the excessed facility for the establishment of its Western Region headquarters in 1954. Remaining cantonments were acquired along with the property. USGS retained the buildings, and by 1959, this particular structure had been adopted for use as laboratory space. It became known as Temporary Structure B or Building 9B.

The original U.S. Army cantonment building had an H-shaped floor plan that probably was divided into two parallel wards connected by a service area with a central entrance lobby. One side of the service area reportedly functioned as a dispensary (Mankinen pers. comm.), whereas the other side may have contained offices and storage space for medical supplies and equipment used in the wards. In 1959, Doell and Cox occupied an L-shaped portion of the building that formerly served as the southern medical ward and the adjoining dispensary.

Temporary Building B is constructed on a thick (18-24 inches) unreinforced concrete slab foundation. It has a low-pitched gable roof with large-end gable vents containing fixed wooden louvers. The exterior walls consist of gypsum wallboard covered with rolled roofing felt held in place with wood battens. The felt cladding has been replaced periodically with composition-rolled roofing. The original wallboard remains largely in place, and 1¼-inch battens are still used to fasten the cladding to the walls. The same gypsum board and cladding material of layered felt or asphalt composition was also used as roofing. In 1979, the original roof was replaced with plywood sheeting and again covered with rolled composition roofing. The exposed rafter ends were trimmed to accommodate fascia board capped with aluminum flashing.

During the 1970s, seven additions were made to the temporary structure, ranging from small, enclosed entry porches, measuring 14 by 14 feet, to a large rectangular laboratory annex approximately 20 by 35 feet in area. The additions were made to the outside perimeter of the original building plan and were used to partially fill in the area between the north and southward divisions. Although the additions are clad in rolled roofing and battens identical to those on the original structure, they are irregular in shape and have aluminum sliding windows of various sizes and placement. The result is a jumbled configuration of old and new that obscures the simplicity of the original H-plan and gives the building an overall ramshackle appearance. This appearance is heightened by the deteriorated condition of the building exterior.

The original building sections are illuminated with evenly spaced rows of large 4/4/4-light windows with sliding wood sashes. Approximately half of these original windows have been removed or blocked by subsequent modifications to the structure. All the original doors have been replaced with the exception of two sets of two- and three-panel, 2/2-light double wooden doors located on east side entry additions. These doors probably were relocated from the building's original entrances or may have been salvaged from a similar type of structure.

The interior walls of the laboratory are painted wallboard, and the painted concrete slab foundation serves as the floor. Small skylights were installed in the roof of the north wing (formerly the dispensary) of the Rock Magnetics Laboratory. The building's plumbing, electrical, and heating/cooling systems were upgraded or replaced during the 1970s and 1980s. The plumbing fixtures in the small lavatory also have been replaced. The overall condition of the interior is poor, evidenced particularly by weak areas and leaks in the ceiling and unrepaired holes and openings in the wallboard.

Rock Magnetics Laboratory Equipment

Field Equipment. Three basic pieces of field instrumentation were used by Cox and Doell to collect core samples: a gasoline-powered core drill, a core lubricator, and a field orienting tool. The presently existing core drill is actually a modified McCulloch Super Pro 81 chain saw and is a later version of the original, which was a McCulloch 35 model. The blade location was fitted with a diamond core bit surrounded by a pipe that ran water over the bit as it drilled into rock. The core drill is not located where the blade of the chain saw was previously; instead, it is located parallel to the drive shaft.

A metal insecticide sprayer was modified for use in lubricating the core hole during drilling. The outtake hose on the sprayer was placed in the pipe on the drill bit during the coring process. This field instrument is original. It is an older model Hudson three-gallon container and is quite dented.

Field orienting tools were used to orient the core and to mark it before it was removed. A tube of brass or aluminum is placed over the drilled core. An attached compass mount (often a modified camera tripod mount) with a clinometer is used to measure the horizontal angle of the core. Magnetic north is then marked on the core with a brass wire before the core is broken off from the rock with a nonmagnetic chisel. A diamond scribe and a felt tip marker serve to make the mark permanent. Hash marks to the right ensure that the core is right-side up. The orienting tool currently used in the Rock Magnetics Laboratory is not original; however, its method of operation is identical to that used in the field by Cox and Doell.

Three-Axis Demagnetizer. The three-axis demagnetizer is a spin demagnetizer that uses electrical currents to remove overlying magnetization from core specimens. Magnetization can result from a number of sources and can mask the original thermoremanent magnetization. The overlying magnetization must be stripped away before the magnetization is measured.

The demagnetization process involves tumbling a core specimen in an alternating magnetic field (Tarling 1983). This procedure causes the magnetization of grains with low coercivity to follow the applied field. The field is reduced while the specimen continues to rotate. As the field is reduced, the magnetization of these particles is left in a random position. More stable thermo-remanent magnetization is left intact.

The three-axis demagnetizer, or tumbler, is a small instrument (approximately one cubic foot) mounted to a table top. It is made primarily of micarta, with nylon screws and additional small parts of Teflon. It is mostly original and was acquired for the research project in the early 1960s. It may have been built by Major Lillard in Washington, D.C. The three-axis demagnetizer uses an alternating current of 60 hertz. It is mounted directly to any table by a circular platform and two supports constructed subsequently by Gromme. These supports contain a cylinder that cradles a circular specimen holder in it. The specimen itself measures 2.49 centimeters in diameter and is 2.28 centimeters long (Doell and Cox 1967b). Specimens are assigned orthagonal axes x, y, and z (with z parallel to the cylinder axis). When the specimen is placed in the specimen holder, these axes are parallel to the cubical edges of the holder (Doell and Cox 1967b). This specimen holder is toothed around the edge opposite the indentation for the specimen. Around the specimen holder are three gears: to the left, on the top, and on the bottom. The gear on the left is driven by a belt on the outside of the cylinder that turns a shaft to which the gear is connected. When the motor is turned on, the gears mesh, rotating the specimen on three axes. The cylinder also contains three coils. The inner and outer coils, which supply the magnetic field, are located around the inner rim of one end of the cylinder. The pickup coil is located on the opposite end of the cylinder, approximately 1½ inches from the specimen holder. The coils have been painted with glyptol for insulation.

The magnetic field is regulated by three devices in the control unit, in series: two variable transformers (Variacs) and an Inductrol (a commercial device made by General Electric). The control unit connected to the three-axis demagnetizer is much more recent than the demagnetizer itself.

Four-Axis Demagnetizers. Two four-axis demagnetizers are mounted to a work table in the Rock Magnetics Laboratory. They are original instruments designed for the research project by Richard Doell and constructed by Major Lillard. The original control units exist. The four-axis demagnetizers function similarly to the three-axis demagnetizer in that they demagnetize cores using an alternating current generated by coils. Instead of rotating around three axes, the core specimen is rotated around four axes relative to the earth's magnetic field. Because the fourth axis is the external axis, however, these demagnetizers, commonly referred to as tumblers, are not four-axis demagnetizers with respect to the demagnetizing field.

The tumblers operate on the same principle as the three-axis demagnetizer. The core sample is put in a specimen holder that is rotated around four axes in a magnetic field. The field is continuously reduced while the specimen continues to rotate. Magnetizations of higher coercivity are left intact, but less stable ones are realigned in a random fashion.

A tumbler consists of three distinct components and the control unit. The instrument is run by a motor, located some distance from the other pieces of equipment to avoid electrical interference. The core is contained in a hexagonal micarta specimen holder that is surrounded by four gears that rotate it on four axes within a rectangular frame. The rectangular frame is mounted on a disc with two pegs protruding from the sides. These pegs lock the unit in the "tank." The tank is a micarta box measuring 11.8 inches square and 5.5 inches deep. A silicone sealant is visible around the edges of the box. The tumbler unit fits into a circular opening on one side of the tank. The pegs, which lock against small tenons, hold the tumbler securely in the tank. Within the tank are copper coils that create the field. These coils are vacuum impregnated with silicone oil to conduct heat away from the tumbler. The remaining area of the tank is filled with silicon oil. The pickup coil is contained in a thin ring of plastic that is cemented onto the side of the tank opposite the opening for the tumbler. On the top of the tank are filler and vent openings, and on one side are two power supply inlets. The tank is attached to a wooden base that is bolted to the table.

Curie Balance. This Curie Balance is used to measure the Curie temperature of magnetic minerals within rocks. The Curie temperature, which varies between minerals, is the temperature at which the mineral loses its magnetism. This instrument was updated in 1966; however, even the unmodified original had little to do with the reversal time scale experiment. It may have been used to determine the Curie temperature before thermal demagnetization was undertaken. The Curie Balance is partly of commercial manufacture and partly constructed by USGS.

The Curie Balance is operated by placing a core specimen in the oven and heating it continuously. The gradient pole pieces (magnets) provide a magnetic field. A magnetized specimen in a constant gradient is subject to a downward pull. Both the magnetization and the temperature are continuously recorded. When the Curie temperature is reached, a loss of magnetization occurs and is recorded on a computer or on a paper tape. The Curie temperature is often indicative of the minerals in the rock.

One of the purchased elements of the Curie Balance is the electromagnet. Two of these were purchased when the lab was set up, and one is dedicated to the Curie Balance. They were made by a company called Spectromagnetic Industries in Hayward, California. The electromagnet is located at the bottom of the Curie Balance. It consists of a soft iron yoke that supports two discs covered with aluminum. These discs are on their edges (like wheels). Within these water-cooled discs are copper coils. A magnet is attached to the interior surface of each of these discs. In the Curie Balance, the electromagnet is turned on its side, with the yoke in back so that there is full access to the area between the magnets.

Between the two discs of the electromagnet is a water-cooled oven that appears as a brass cylinder. This is where the core specimen is suspended. The curved and straight individual pole pieces or pairs of magnets (humorously referred to as Marilyn, Audrey, Phyllis, and George) are placed between the discs of the electromagnet to provide the magnetic pull on the specimen. Above the oven is a vacuum tube that allows materials to be heated in oxygen, in another gas, or in a vacuum.

The glass bubble on the top of the Curie Balance is an Ainsworth Automatic Recording Balance. It is an analytical balance that changes weights automatically to continuously record the weight of the specimen because cores sometimes lose weight when they are heated. This machine is fully automatic, requiring fewer man-hours to operate than other instruments. Some features that make it automatic are programmed control of the magnetic field, automatic recording of the force acting on the speciment, and programmed control of the heating and cooling cycle (Doell and Cox

1967c). It is often used to screen specimens before they are subjected to the more labor-intensive process of thermal demagnetization.

The control unit for the Curie Balance has been updated since 1966. The electromagnet control panel on the lower left side is original, as are the oven controls just above it.

Pole Pieces. There are four pole pieces, or pairs of magnets, in the Rock Magnetics Laboratory that, because of their hyperbolic shapes, have been playfully named Marilyn, Audrey, Phyllis, and George. They are used in the electromagnet in the Curie Balance. They are constant gradient pole pieces with gradients arranged in factors of three. All are original and were designed by Doell and constructed by Lillard in the Rock Magnetics Laboratory. In the Curie Balance, these magnets function to pull the heated sample magnetically, allowing the Curie temperature to be measured.

Each pole piece weighs approximately 5 pounds and is 4 inches in diameter. They consist of two disc-shaped magnets that are mounted in a soft iron yoke with approximately an inch of space between them. A coil of copper wire on micarta encircles the left disc of each. This coil acts to counteract the residual field of the iron. The names of the pole pieces are impressed on self-adhesive plastic tape and applied to the yokes below the copper coils. "Marilyn" is the most strongly curved pair, followed by "Audrey." The curvature of "Phyllis" is not visible to the naked eye. "George" is even straighter than "Phyllis." These varying degrees of curvature serve to move the centerline of the hyperbolic focus further downward, decreasing the strength of the pole pieces' magnetic gradients.

Rubens Coil. The Rubens coil provides a field-free zone in a coil array. The function of the Rubens coil is to cancel the earth's magnetic field for thermal demagnetization of core samples. It is constructed of nonmagnetic materials, and the control unit is placed far enough away from the instrument to avoid interference from its metal components. Although the coil array of the instrument is original, the control unit was constructed in 1969. The ovens (located in the coil array) for thermal demagnetization are also later additions. The coil array was built by Doell and Lillard with the assistance of a student named Brian Norton. Gromme speculates that the woodwork was probably done by Doell at his home. The control unit was designed by Nathaniel Sherill at USGS, replacing an array of submarine batteries that provided power to the Rubens coil when Cox and Doell were using it.

The Rubens coil was operated by Cox and Doell during the period of significance, but not necessarily in the reversal time scale experiment. They used it for experimental demagnetization of volcanic rocks to search for evidence of self-reversal and found none. They may have used this device to some extent to thermally demagnetize rocks before examining them in the spinner magnetometer, but according to Gromme, that would not have occurred often.

The wooden cage provides a framework for two sets of wire coils that generate a magnetic field. The inner coils have a constant current supplied by the power source and create a field. At the moment of adjustment, that field cancels out the earth's magnetic field. Fluxgate magnetometers inside the Rubens coil detect any disturbance through a negative feedback loop. That information is fed to the second, outer set of coils, which correct for the disturbance.

The coil array consists of an open wooden frame held together with brass screws and aluminum hardware around which bell wire is wound. It is square (approximately 8 by 8 by 8 feet) and reaches from the floor to the ceiling. The frame consists of 10 (E-W and N-S) vertical and five horizontal planes with two diagonal supports on each side. Two coils of bell wire are wound around each wooden square. The only original equipment remaining inside the coil array consists of three fluxgate magnetometers that were commercially built to the design of Serson and Hannaford (of the Canadian Geological Survey). These rest in a micarta holder.

The only remaining original component of the control unit is the control panel for the fluxgate magnetometers. This panel is located near the top of the right-hand side of the control unit. It was made at the same time as the fluxgate magnetometers. This panel has four sections. Three of them are component amplifiers for the three axes of the earth's magnetic field, and the fourth is a monitor that displays disturbances in the field-free zone.

Spinner Magnetometers. A spinner magnetometer is used to determine the intensity and direction of remnant magnetization within core samples. Two spinner magnetometers are in the Rock Magnetics Laboratory, located against the walls and on opposite sides of the room. They are mounted on small supporting piers of concrete brick masonry constructed on the concrete laboratory floor. These particular magnetometers are second generation. They were designed by Doell in 1963. The original magnetometers were slightly different in design but operated in a nearly identical manner. Separate control units are located adjacent to the spinner magnetometers. Each control unit contains a cathode-ray oscilloscope that displays lines representing three-phase signals. However, most of the components in these control units have been replaced since they were acquired by USGS in the early 1960s.

The spinner magnetometers operate by spinning core specimens near a pickup coil at one end of a cylindrical shaft. The rotating magnetization induces a current in the specimen pickup coil. A pair of magnets at the other end of the shaft feeds a three-phase signal to the reference pickup coil. The signal from the reference pickup coil is passed through a phase shifter (that shifts the output phase at angles from zero to 360 degrees with respect to the input phase angle) and then through a voltage attenuator (that varies the reference signal amplitude). This output is added to the signal from the specimen pickup coil in a mixing circuit and the sum is amplified, filtered, and displayed on a cathode-ray oscilloscope). The amplitude of the current depends on the intensity of the magnetization of the specimen, and the direction within the plane is given by the phase angle (Tarling 1983:84). The phase shifter and the attenuator are adjusted until the sum of the two outputs is zero and the "Lissajous figure" (lines on the oscilloscope) form a single line. In this way, through null detection, an unknown core specimen's magnetic signal is determined by comparison with a known reference signal (Doell and Cox 1965).

Six measurements are taken on the magnetometer by inserting a core specimen in six different directions. These six measurements are then reduced to three by averaging the opposite measurements. Today, these data are fed into a computer. In the early 1960s, they were hand-calculated with the aid of equal area nets, one or two of which still remain in the laboratory. Equal area nets are simply rotating lucite circles specially designed for plotting phase angles given by the spinner magnetometer readings. The common intersection of the three readings indicates the direction of magnetization of the core specimen. Doell designed and fabricated the equal area nets himself in the early years of the research project (Gromme pers. comm.).

Distinct physical components of a spinner magnetomer include a clear plastic specimen holder that fits into a circular micarta head (roughly 1½ inches in diameter) located at one end of a 16-inch cylindrical shaft. The micarta head rests on a 6-inch disc that contains the specimen pickup coil. The specimen pickup coil is astatic and is made of copper wire wound on an acrylic Plexiglas form and sealed in an acrylic monomer. Then another form is attached and the outside coil is wound around that. Covering the entire disc is aluminum foil that is cut to form an inverse starburst on the disc. The aluminum foil minimizes electrostatic interference, and the presence of the sunburst eliminates eddy currents that would oppose the rotating magnetic field of the specimen, canceling it out so that no signal would be picked up. The entire pickup coil disc is painted white.

The shaft is constructed of epoxy glass and aluminum and is covered with an aluminum casing. It rotates on two bronze bushings mounted in a brass bearing support. At the other end of the shaft is a three-phase bipolar generator. This soft iron cylinder contains two alnico (aluminum, nickel, and cobalt) magnets that are in astatic arrangement. Pickup coils located close to these magnets in the cylinder pick up a three-phase signal. The generator is roughly 2½ inches in diameter. On the exterior of the cylinder are 12 paired screws that attach the coils on the inside. A plexiglass shield is attached to the pier on which the instrument rests, shielding the spinning head and pickup coil. An aluminum pulley is attached to the shaft near the generator. A belt is attached to a second pulley that is connected to a shaft driven by an induction-type motor. The motor is located roughly 2-3 feet away from the instrument. The entire spinner magnetometer, not including the driving motor, is approximately 20 inches long.

The components of the adjacent control unit have been largely replaced since the reversal time scale research project took place. The phase shifter is a commercial unit commonly used in servo-system applications and is called a Synchro. The decade attenuator is a commercial type of voltage attenuator. The amplifier is a commercial unit with low-input noise level and adjustable gain from zero to 85 decibels. The oscilloscope is a later (1970s or 1980s) addition to the control unit.

Mass Spectrometer. The mass spectrometer measures the relative amount of argon isotopes in a sample of argon that has been extracted from a specimen of rock to be dated. The dating equipment has since been removed from the laboratory. The only original piece of equipment that remains is the glass flight, or analyzer, tube of the mass spectrometer. It was hand blown at UCB by Morely Corbett.

To obtain a radiometric date, an argon sample is introduced into the small glass end of the flight tube. In the ion source area, the gas sample is bombarded with electrons, producing positively charged ions. These ions are then accelerated through the vacuum tube. A magnet is placed on either side of the tube at the curved section. This process causes the ions to separate by atomic weight and form separate streams through the tube. One stream is channeled into the metal collector cup at the opposite end of the tube. The ionized atoms "take" their missing electrons from the cup, producing an electrical signal that can be measured. Varying the strength of magnets channels different streams of ions into the cup. The ratio of argon isotopes then yields a radiometric date.

The mass spectrometer is made of glass and nichrome (a nickel-chrome alloy). The introduction end of the flight tube is glass. The entry point for the argon gas is narrow but soon widens to a central portion with six protruding glass nipples. Housed within this wide glass portion is the ion source (which bombards the sample with electrons to produce positive ions, accelerates them, and focuses them into a narrow beam) (Dalrymple and Lanphere 1969, Parkinson 1983). The glass flight tube curves at roughly 90 degrees. At the other end is the collector cup, a nichrome cylinder. A straight glass connecting tube runs between the introduction end and the collector cup for support.

A number of control units were used in conjunction with the mass spectrometer, but none remain in the Rock Magnetics Laboratory. These control units regulated the many parts of the mass spectrometer and displayed the output, or ratio of argon isotopes.

PART 4. SOURCES OF INFORMATION

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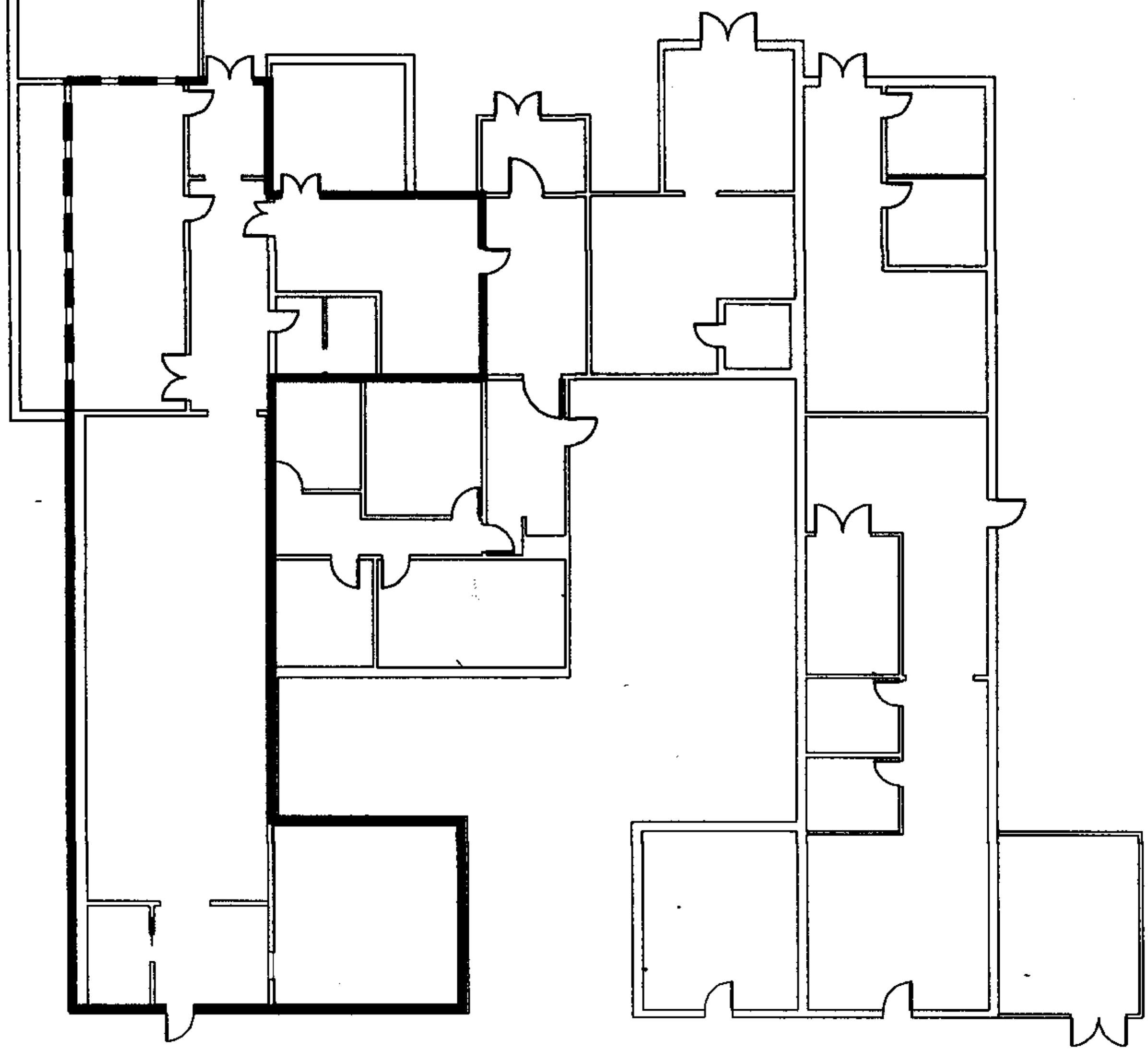
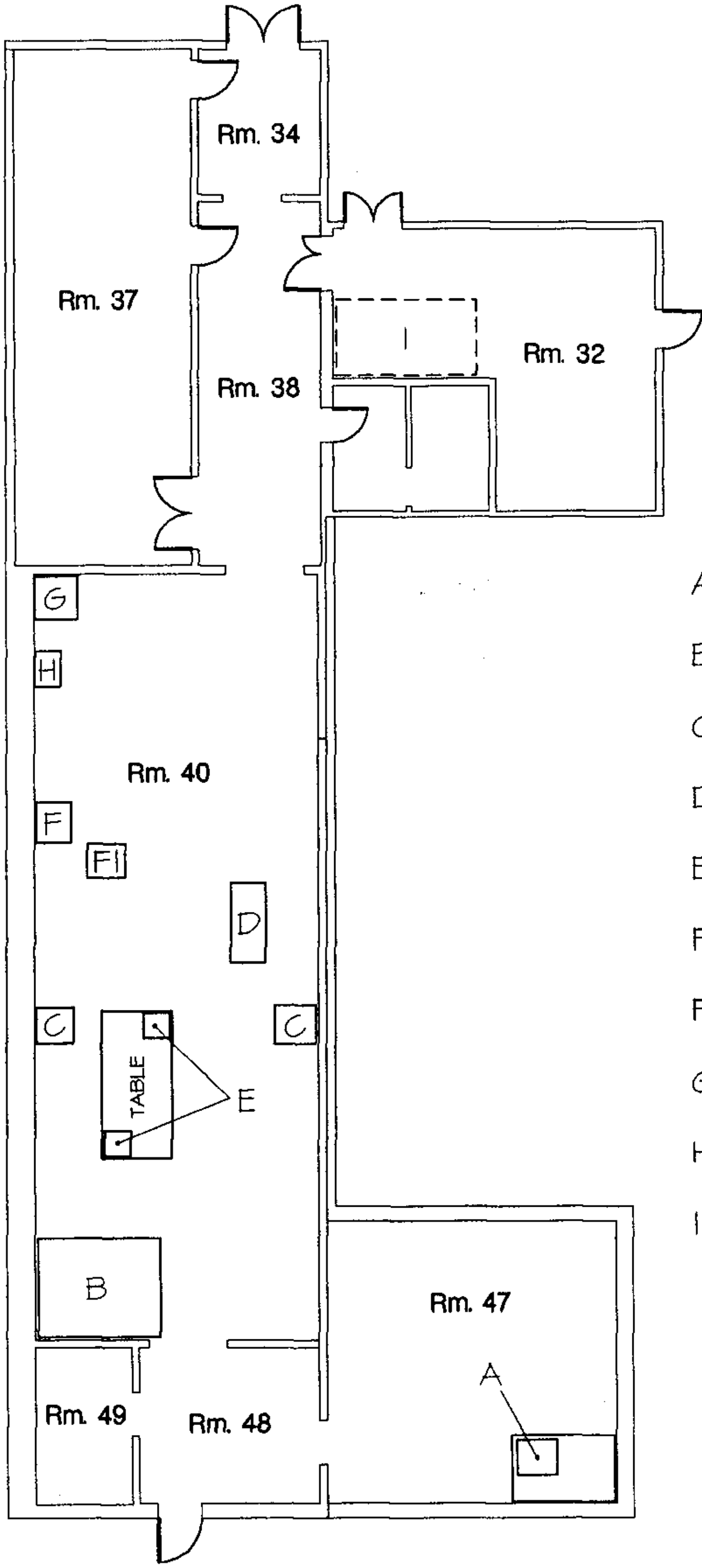


BUILDING B - ROCKMAGNETICS LABORATORY

Scale: 1" = 20'



A. Three-axis demagnetizer.

B. Ruben's coil.

C. Spinner magnatometer (2).

D. Control unit for Ruben's coil.

E. Four-axis demagnetizers (2).

F. Curie balance.

FI. Control unit for Curie balance.

G. Spectromagnet.

H. Magnets for Curie balance.

I. Former location of argon masspectrometer.

BUILDING B - ROCKMAGNETICS LABORATORY - EQUIPMENT LOCATIONS

Scale: 1" = 12'